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Fabrication of Waste Ceramic Reinforced Polymer for Electrical Insulation Application and Characterization of the Mechanical and Physical Properties

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Abstract

Composite materials continue to be the forefront materials for many manufacturing industries. Due to their superior mechanical and physical properties, composite materials play a significant role in modern manufacturing technology. However, the cost of composite materials is seen to be a major challenge. In this thesis, waste floor tile ceramic particles are used as a reinforcement, so that a problem related to cost can be solved and sees a new way to manage construction ceramic waste materials. The main goal of this research is to propose a new composite material with an optimal physical and mechanical response for a low-voltage pin-type insulator. The ceramic reinforcement is prepared by crushing waste tiles with a stone crusher machine and sieving the powder under an average particle size of Ø<0.5,0.5< Ø <1, and 1< Ø <2mm diameter. Characterization of major and minor oxides- concentration in the ceramic powder is determined using a complete silicate analysis. Then the reinforcement ceramic is added to a general-purpose epoxy resin-1003 with 30%,35%, and 40% by weight. Experimental test samples are fabricated using a stir-casting technique. Taguchi L9 OA design of experiment is used for designing each experimental sample. Experimental analysis of physical properties such as water absorption and electrical resistance, specifically dielectric strength is investigated. Further mechanical responses such as flexural strength, and compressive strength are investigated. Finally, Minitab software is used to optimize process parameters. The research shows reinforcing 0.5<Ø<1 mm ceramic particles with 30%wt, exhibit an optimum flexural strength of 142.788 Mpa, compressive strength of 85.64Mpa, water absorption of 0.3% along with dielectric strength of 5.92Kv/mm. The research findings show a promising leap in the way waste ceramic tiles can be recycled and utilized for electrical insulation applications.

Key words/Phrases: Composite; CRPM; Epoxy Resin; Electrical insulation; Dielectric strength

1. Introduction

The ever-growing demand for new and advanced materials has ceased the way for discovering new types of materials with superior properties. Lightweight, better strength, flexibility, thermal and electrical insulation/conduction, durability under any working conditions, etc. are some of the required properties for a new material. However, it is not an easy task to acquire such desired properties from a single pure material. As any pure material has its own desired property it also has its undesired weak property.

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For example, ceramic materials are known for their brittleness, hardness, heat resistance, electrical resistance, and fractural strength those properties can be desiring or limiting depending on the type of application they are used for. On the other hand, there are polymer materials known for their flexibility, ductility, low hardness, low heat resistance, and stiffness. So, if a new material is to be designed with the superior advantage of having both ceramic-polymer-like properties it falls under the category of composite manufacturing technology. By careful process design and analysis of matrix polymer material and its ceramic reinforcement, it is now possible to acquire a ceramic-polymer composite material with high strength, good thermal response, lightweight, and corrosion resistance as compared to other types of metal matrix and ceramic matrix composite materials[1].

Over the past decades, studies have shown the growing demand for ceramic-polymer composite. Ceramic-reinforced polymer composite has shown a great deal of attraction in thermal, mechanical, morphological, and wear resistance behavior [1]. Polymers are usually the matrix materials in a composite due to their viscosity[2].

There are two classifications of polymer materials, called thermosetting and thermoplastic polymers. Thermosetting polymers are known for their irreversible appearance after initial heat curing. Once a liquid form of the thermosetting polymer is cured it will solidify. Subsequent addition of heat will cause the materials to degrade instead of melting or softening. Epoxy, Vinyl ester (VE), Phenol formaldehyde (PF), Polyurethane rubber, etc are some of the thermosetting polymers[2]. On the other hand, there are thermoplastic polymers, known for their reversible appearance. Reheating after the initial heat treatment results in softening and change state inserted of molecular degradation, making them easily mouldable and recyclable. Acrylonitrile styrene acrylate (ASA), High-density polyethylene (HDPE), Polybutylene (PB), and Polyethylene terephthalate (PET) are some examples[2].

Careful analysis of a proper polymer matrix with the right type of reinforcement can help obtain a new type of composite material. Several researches have shown adding different types of filler materials such as metal, non-metals, ceramics, etc. to a polymer matrix exhibits superiority in mechanical and electrical behavior[3-5]. Those materials can be used as a replacement for traditional metal and other materials. Electrical insulating composite materials are widely used in aerospace engineering [5], electrical power plants, automotive industries, energy production industries[4], metallurgy [6], and chemical industries[7].

Electrical insulating materials play a significant role in preserving energy loss and effectively transmission and distribution of electric power[7,8]. Insulating materials are seen as a wire coating in different electronic instruments. Dielectric properties and reliability are the most essential features required from an insulating material [8]. Polymers are the most famous types of insulating materials. Easy moldability, flexibility, and high dielectric strength make them the preferred type of insulating materials [10].

Over the past decades, several researchers have implemented polymer materials reinforced with inorganic fillers to improve their mechanical and dielectric strength. Amin et al [11] showed that reinforcing micro and nano silica fillers greatly improved the dielectric and mechanical strength of epoxy polymer making it applicable for high voltage insulation. The insulating capacity of epoxy/micro-silica was also studied by J. Parks [12]. Adding 70wt% spherical type micro silica was observed to give high electric insulation breakdown strength. It is seen that the amount of inorganic filler content, particle size, and microstructure influence the electrical properties of polymer materials.

Ceramic reinforcement to polymer materials is seen to affect the electrical resistivity of polymer materials. Jia et al. [13] studied the electrical resistant properties of polymer-derived ceramic reinforced with boron nitride nanotube. The electric resistance was seen to increase from 106 Ω•m to 108 Ωm. Reinforcement materials such as mica flake, trihydrate, glass, kaolin, calcium carbonate, and alumina are commonly used for electronic applications[9]. To have a cost-effective insulating material, reusing waste ceramic products as a filler material is a great solution.

Aman et al.[9] used waste glass (SiO2). seashells (CaCO3) and, polypropylene to fabricate high-voltage insulating structures. An optimum composition ratio of 65/35 PP–AW wt% gives an insulating breakdown strength of 14.76 kV/mm. A. Rybak [14] investigated the electrical resistance of composite material constructed from epoxy resin and core-shell ceramic fillers. It was seen an increase in dielectric strength by 16%.

Using inorganic solid reinforcement effectively enhances the insulation capacity of a polymer matrix [8]. Silica inorganic filler material in micro or nano size is seen to improve the mechanical, electrical, and thermal behavior of composite material[11]. Li Chen et al.[15] introduced core-shell (SiO2-GO) into an epoxy matrix to study mechanical properties. Those inorganic filler materials are seen to greatly enhance the mechanical strength of the polymer matrix. An investigation of a Hallow-type silica filler on an electric insulating capacity of epoxy was investigated by Murakami et al.[16]. Adding hallow-type silica confirmed a decrease in brake-down strength of normal epoxy under electrostatic capacitance measurement.

Khan et al.[17] investigated the mechanical and physical response of silicon rubber reinforced with micro-alumina-trihydrate (ATH), micro silica, and hybrid-sized particles. Results have shown that 15µm ATH-Si-rubber reinforcement has a higher surface resistance of 8.4x1015 Ωcm and dielectric strength of 9.8x1015Ωcm. By using ceramic silica the electrical resistance capacity of an epoxy-based composite can greatly be improved. Before using ceramic-polymer composite material for outdoor insulation applications electrical resistivity or dielectric strength test must be conducted.

According to previous research, little is known about the insulating quality of crashed waste ceramic reinforcement to epoxy polymer. This research investigated the mechanical and physical response of new insulating material constructed from waste ceramic/polymer matrix specifically used for low voltage pin-type insulating material.

2. Methodology

2.1. Raw Materials

2.1.1. Ceramic Reinforcement

For the production of the intended composite material, waste floor tiles ceramic material was prepared as a reinforcement. Waste floor tiles ceramics were collected from the backyard of a construction site. Since different ceramic products are seen dumped together, identifying similar ceramic products was done. After carefully separating similar ceramic products, the floor tiles were dry cleaned from dust particles and unnecessary construction debris which may affect the purity of the ceramic. Finishing separating and cleaning the ceramic products, the floor tiles were manually crushed. Then manually crashed ceramics were fed into a 2.2kw drive motor stone crusher with three rounds of cycle to obtain the desired filler size.

Then, machine-crashed ceramics were sieved under 0.5, 1, and 2 mm diameter sieve holes. And ready for further processing as seen in Figure 2. Finally, After a week of sun drying the ceramic particle was further dried inside an electrical thermostatic heat dry box at 100^0C for 1hr. The heat treatment process ensures the removal of moisture from ceramic particles and allows better solid-polymer cohesion

a) b) c)

Figure 2. Crashed and sieved waste floor ceramic tiles, a)Ø<0.5, b) 0.5< Ø <1, and c) Ø>1mm diameter ceramic particles

2.1.2. Waste Ceramic Characterisation

To understand and characterize the waste ceramic material, a complete silicate analysis is conducted. The analysis indicates the major and minor oxides available in the ceramic powder. Based on the machine analysis, the main elements in percentage are listed in Table 1.

Table 1 Complete Silicate Analysis Report

Elements	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2O	LOI
percentage (%)	68.10	18.60	3.22	2.84	0.60	1.94	2.52	<0.01	0.08	0.84	0.27	0.54

As it can be seen from Table 1, Si_2O and Al_2O_3 are the major elements covering almost 90% of the entire composition. Silicon oxide (silica) is to be a major building block for many synthesized ceramic materials. In several researches, silica was used as a filler material on epoxy polymer[8,10,11]. As seen by previous researchers, an improvement in mechanical and physical strength was seen by introducing silica fillers to the polymer matrix. Due to the high thermal and electrical resistance silica has, it is frequently seen as a reinforcement to improve the properties of epoxy polymer. Silica is widely recommended as filler ceramic for outdoor insulation, which makes the entire structure not only suitable for electrical insulation but also provides good thermal stability and improves mechanical strength[11]. Thus since silica covers 70% of the ceramic filler reinforcement, an improvement in electrical and mechanical property is expected.

2.1.3. Polymer Material

1. For this study epoxy inorganic polymer was selected due to the unique properties it exhibits. Some of the epoxy polymer properties are discussed below[20,21].
2. It has very good electrical resistance.
3. Excellent adhesive properties with ceramic, wood, and metal materials.
4. epoxy resin increases water resistance to a structure
5. Lightweight and viscoelastic nature

Good electrical resistance stability is an essential parameter to use the material for electrical insulation applications. Due to such properties, epoxy resin was selected for the study. For preparing test samples, 3 liters of general-purpose epoxy resin-1003 was purchased from the World Fibre Glass Company (WFG)located around Gurdeshola, Addis Ababa.

2.1.4. Hardner Material

Hardener material is important to solidify a polymer material at room temperature. A 300ml of general-purpose polymer hardener was purchased from the same place epoxy resin was purchased.

2.1.5. Fabrication of Waste Ceramic-Polymer Composite

The test samples were prepared by initially weighing the right weight composition and particle size ceramic particles with epoxy resin as seen in Figure 3a. Then mixing ceramic-polymer material was done using a mechanical workshop drilling machine at 380rpm for 5min, to maintain a homogeneous mixture as seen in Figure 3b. Then hardener material is added by a 30:1 ratio to the entire volume of the mixture.

a) b)

Figure 3 Wighting composition of polymer and ceramic fillerb) Mixing epoxy and ceramic using workshop drill machine

Each test sample was prepared by the following combinations shown in Table 2. for 300g of the total mixture. To determine an optimal process parameter Taguchi method in Minitab software was implemented. The Taguchi OA method avoids unnecessary bulky test samples that will be obtained while using a full factorial method and helps to easily plot and determine the optimal process parameter. Having three input parameters such as waste ceramic particle size, weight percentage of epoxy resin and weight percentage of ceramic reinforcment with three distinguished levels, the L9 orthogonal array was selected.

Table 2 Design of experiment for test samples

Sample I	Ceramic size Ø<0.5mm	
	Epoxy resin (70%) 0.7x300=210g	Ceramic reinforcement(30%) 0.3x300=90g
Sample II	Ceramic size 0.5 <Ø<1 mm	
	Epoxy resin(70%) 0.7x300=210g	Ceramic reinforcement(35%) 0.35x300=105g
Sample III	Ceramic size 1<Ø<2 mm	
	Epoxy resin (70%) 0.7x300=210g	Ceramic reinforcement(40%) 0.4x300=120g
Sample IV	Ceramic size0.5<Ø<1mm	
	Epoxy resin (65%) 0.7x300=195g	Ceramic reinforcement(30%) 0.3x300=90g
Sample V	Ceramic size 1<Ø<2mm	
	Epoxy resin (65%) 0.65x300=195g	Ceramic reinforcement(35%) 0.35x300=105g
Sample VI	Ceramic size Ø<0.5mm	
	Epoxy (65%) 0.65x300=195g	Ceramic reinforcement(40%) 0.4x300=120g
Sample VII	Ceramic size 1<Ø<2mm	
	Epoxy (60%) 0.6x300=180g	Ceramic reinforcement(30%) 0.3x300=90g
Sample VIII	Ceramic size Ø<0.5mm	
	Epoxy (60%) 0.6x300=180g	Ceramic reinforcement(35%) 0.35x300=105g
Sample IX	Ceramic size 0.5<Ø<1mm	
	Epoxy (60%) 0.6x300=180g	Ceramic reinforcement (40%) 0.4x300=120g

3. Results and discussion

3.1. Mechanical Test

3.1.1. Flexural Strength Test

To analyze the bending strength of the test samples the machine has been set up to a three-point bending with a crosshead moving speed of 0.5mm/min. An ASTM D710 (170x13x6mm) standard was used to determine the cross-section of the test sample [20](*see Figure 4a).* After setting the samples, the flexural test was conducted on a computer- controlled electromechanical universal testing machine (IE linan testing equipment 250101, china)(*see Figure 4b*).

1. b) c)

Figure 4 a) Prepared samples for flexural testing b) A three-point flexural test before load applying c) A three-point flexural test after applying load

A mathematical equation for determining the bending force is given by the equation below [21].
A mathematical equation for determining the bending force is given by the equation below [21].

$\delta t =$ $3F/2Wt^2$ … Equation 1

Where δt =bending strength ,F= maximum load applied, L= span, length (150mm) W= width(13mm), t= is thickness of the sample(6mm).

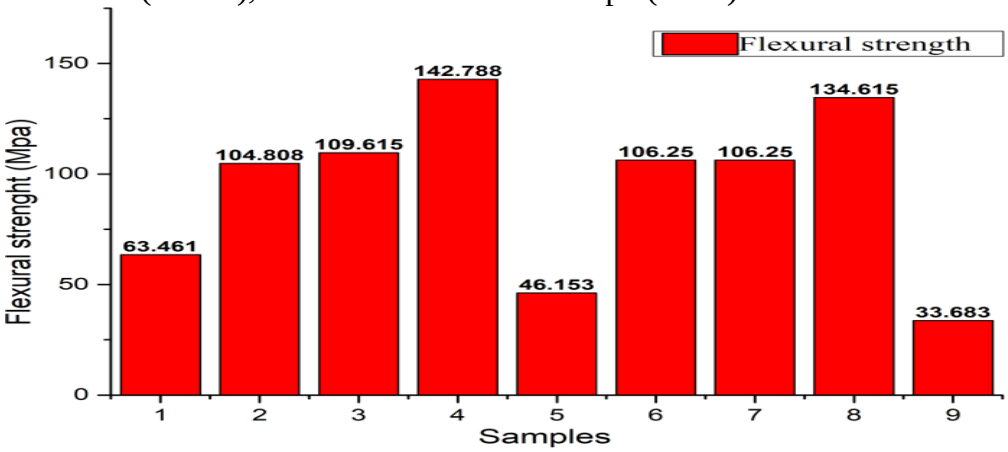


Figure 5 Type of composite samples and their corresponding flexural strength

As seen from Figure 5, the flexural strength was significantly affected by filler content and particle size. A composite material constricted with filler Ø<0.5, 30% ceramic, and 70%wt resin ratio experiences less flexural strength compared to the other samples. The flexural strength for filler size Ø<0.5 ranges between 63.5-33.6Mpa, which shows a decrease in flexural strength by 36% with an increase in filler content and a decrease in resin concentration. The particle size in this range maintains a higher homogeneous mixture resulting in higher brittleness of the sample and resulted in low flexural strength. The composite sample constricted from filler size of 0.5< Ø <1mm had the highest flexural strength ranging from 109.6-142.7Mpa. When the filler content increases a decrease in flexural strength by 30.2% was seen. Finally, ceramic filler with the highest filler size (1<Ø<2mm) had a modest strength ranging from 62.5-106.2Mpa. which showed a decrease in strength by 69.9%.

As discussed earlier the highest flexural strength (142.8Mpa) was maintained with a ceramic filler size of 0.5<Ø<1 mm, and 30%-65% ceramic-resin weight concentration. This increase in strength is due to higher surface area agglomeration with this particle size. Therefore higher surface area energy is produced at the filler-matrix interface[22]. Furthermore, the mechanical strength is dependent on the stress transfer between the polymer matrix and ceramic fillers[14]. During applying bending load stress will concentrate on the lower section of the test sample which will be exposed to tensile stress. As loading increases crack will initiate and propagate through the entire thin section of the structure (thickness). Since the larger size filler in sample 4 compared to sample 1, the filler ceramic was weighed under the matrix where tensile strength was developed. This ceramic filler concentration was able to

strongly withstand the bending load and cause higher flexural strength before failure. This phenomenon was seen in this experiment

3.1.2 Compressive Strength Test

The compressive strength is a distractive test that is used to determine the maximum load the material can handle without buckling and braking. The compressive load was applied to the longest axis of the test samples. The load gradually increases till failure occurs, this setup for the test can be seen in Figure 6b. For this part of mechanical strength characterization, an ASTM-D695 standard was used[23](25x25x10mm). Prepared rectangular crossectional test samples can be seen in Figure 6a. The compressive test was conducted on a universal testing machine (IE linan testing equipment 250101, china).

Figure 6 a) Compressive strength test samples b) Setup for compressive test The compressive strength can be mathematically equated by the equation below [24].

$\delta c = F$ Equation $2bh$

Where δc= compressive strength, F=ultimate breacking force, b=width and h=thickness of test samples.

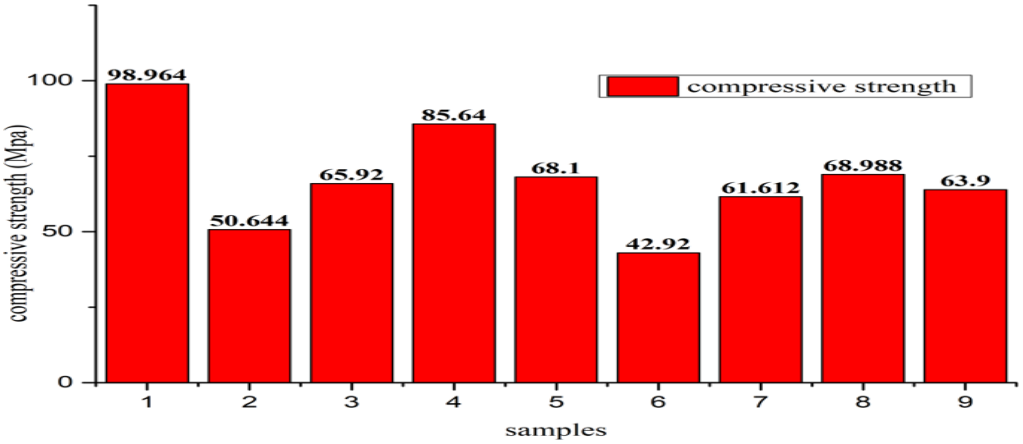


Figure 7 Type of composite samples and their corresponding compressive strength

As seen in Figure 7, the maximum compressive strength(98Mpa) was recorded by sample #1, which was prepared from 30-70wt% resin ceramic concentration with Ø<0.5mm reinforcement particle size. This result was seen due to the homogeneous mixture of filler ceramic particles with a polymer matrix. As the filler size was smaller, a homogenous mixture between reinforcement particles and polymer matrix was created. Resulting in a strong bond between filler ceramic and matrix. Finally, this strong bond made the material withstand high compressive loading [25]. The compressive strength was seen to have a direct relation with filler size and a reverse relation with filler weight percentage concentration (Wt%). Absorbing the destroyed test samples, a crack was seen to develop along the axis of the polymer matrix. This was because the incorporation of ceramic fillers

bears a higher strength of withstanding compressive loading and transmits this load to the matrix.

For sample #1 (Ø<0.5mm,70/30wt%) decrease in strength by 54.87% was seen as filler concentration increased from 30 to 40wt%. Progressively for filler size between 0.5 and 1mm, the compressive strength was seen to show a decrease by 29.91% as the filler concentration increased from 30 to 40%wt concentration. As for the final sample (1<Ø<2mm), a decrease in strength by 43.55% was seen as filler concentration again moved from 30wt% to 40wt% concentration.

Comparing each sample, a decrease in compressive strength by 60.62% was seen as filler size increased from Ø <0.5 to 1<Ø<2 mm, indicating filler size had the highest effect on compressive strength.

3.2. Physical Test

3.2.1. Water Absorpation Test

This experiment helped to understand the hydrophobic behavior of the polymer material with ceramic reinforcement. The water resistance behavior is an important response that needs to be studied for polymer-based insulators [17]. To determine the sample that was more hydrophobic a calculation is done using the moisture absorption formula(see Equation 3). The weight of each sample before and after water immersion was measured. Then, the average percentage of water absorption was calculated.

$$\text{Water Absorption (\%)} = (Wa - Wb)Wb \times 100 \qquad \text{Equation 3}$$

Where Wa = weight of the composite sample after water immersion, Wb = weight of the composite sample before water immersion.

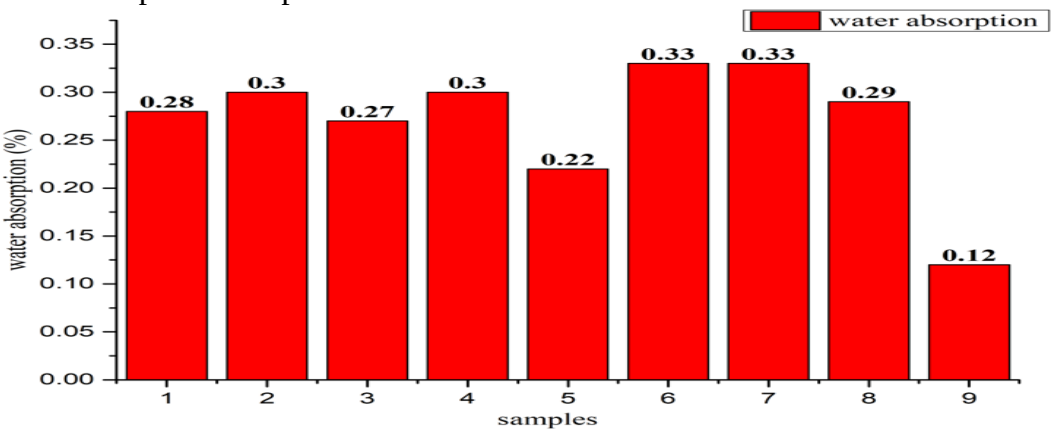


Figure 8 Percentage of Water Absorption of Each Test Sample

From the results obtained and from the graph it can be understood that when the particle size increased the value of water absorption also increased. When the ceramic size is bigger, it leaves more surface for the water molecules to interface and immerse inside the ceramic body. As a result, it creates heavier body mass for the entire structure. This causes a larger weight variation between dry and wet samples. So, ceramic particle size 1<Ø<2mm had the largest water absorption value of 0.33%. this result shows 7.85% more water intake ceramic with Ø<0.5 filler size.

The filler concentration had a direct relation with water absorption. As seen from the graph Figure 8, 30%wt ceramic fillers had the highest water absorption. For all particle sizes, the value of water absorption was seen to increase with an increase in ceramic filler quantity.

3.2.2. Dielectric Strength Test

This experiment helped to understand the maximum voltage the test sample can withstand without losing its insulation characteristics [26]. A power frequency standard test machine (TERCO S-141 05 Huddinge Stockholm, Sweden) was used to determine the breaking voltage. The test for measuring the dielectric breakdown voltage for a solid sample was conducted using the ASTM D149 – 09 standards (50 mm diameter with 10 mm thickness) [27]. To avoid the effect of heat the test was conducted under 25-800Hz frequency. The temperature was kept under ambient temperature (25±10c). the setup for the test is shown in Figure 9.

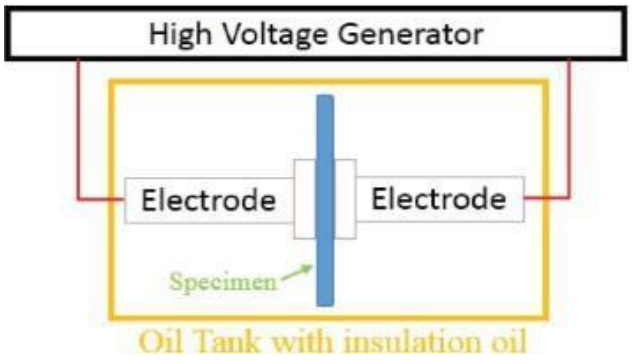


Figure 9 High-Voltage Breakdown Set up[26]

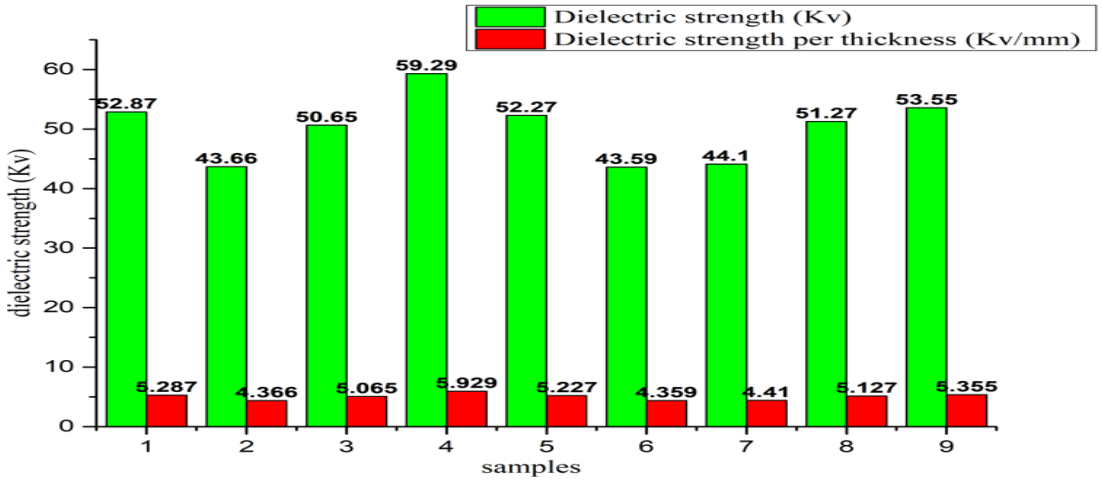


Figure 10 Recorded dielectric strength for each test sample

Adding silicon-based ceramic contributed to the dielectric strength of the composite material[11]. Which was the highest when the filler size was modest. The dielectric strength is mainly associated with the quality of particle dispersion across the polymer matrix[9]. From the experiment, the maximum value of 59.29Kv (5.929Kv/mm) dielectric strength was observed by an epoxy reinforced with Ø<0.5<1mm filler with 30%wt concentration. As the size of filler ceramic reinforcement increases, the

dielectric strength of the structure was seen to increase from Ø<0.5 to 0.5< Ø<1mm. However, it was seen a decrease in dielectric strength when filler size was increased from 0.5< Ø<1mm to Ø>1mm. A similar observation was seen in previous research[9]. Noraiham et al.[28] mentioned in his research, adding a smaller number of filler materials forms agglomeration with the polymer matrix creating rich dispersion along the structure. This agglomeration of deposited ceramic reinforcement creates a current barrier, which results in insulation of voltage. As the particle size was increased from less than 0.5mm to Ø<0.5<1mm, the ceramic particles seemed to act as a current blockage. The dielectric strength is the function of filler dispersion. In some cases, further increase of filler materials creates un-homogeneous mixture along the composite structure and reduces the dielectric strength[29]. This is a logical explanation for the results seen by the present study. As seen from Figure 10, when filler size increased from a diameter less than 0.5mm to a diameter between 0.5 and 1mm at a filler concentration of 30wt%, an increase in dielectric strength by 12.14% was observed. As the filler size was between 1 and 2mm the dielectric strength was decreased by 34.44% which was 1.3 times smaller.

3.3. Optimisation of Process Parameters

3.3.1Taguchi on Grey Relation Analysis

For the present study, four responses were conducted. To analyse the grey relation several steps are followed. The signal-to-noise ratio was initially conducted. Depending on the type of characteristics needed to be studied, there are three types of S/N ratios [18].

I- Smaller- The Better:- calculated by the equation below.

$$\frac{S}{N} = -10\log\frac{1}{n}\sum y^2 \quad \text{.....Equation 4}$$

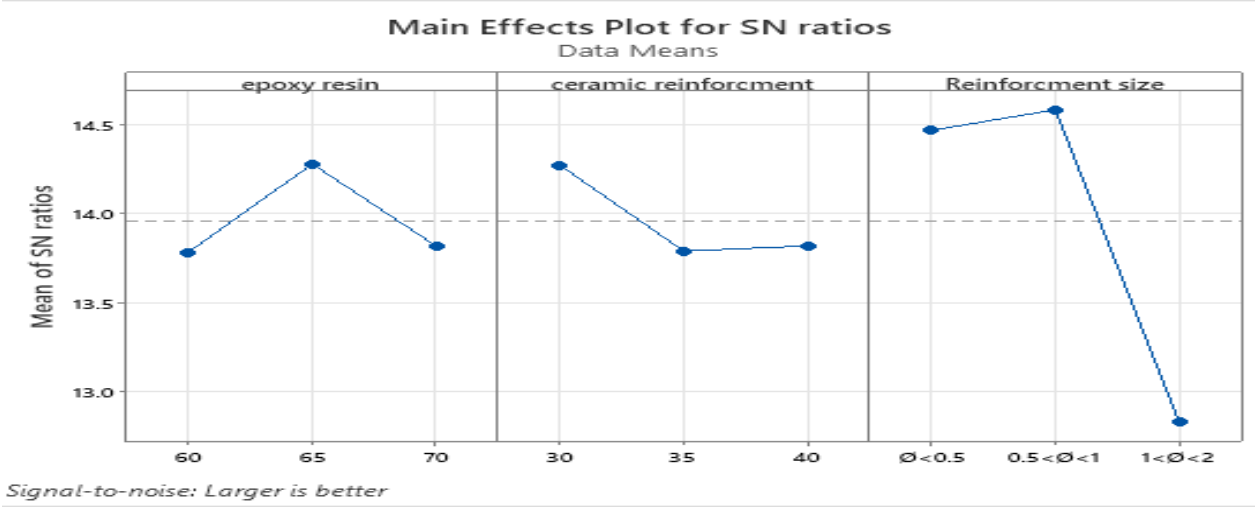
II- Normal-The Best:- Calculated by equation below

$$\frac{S}{N} = 10\log\frac{y}{\delta^2} \quad \text{.....Equation 5}$$

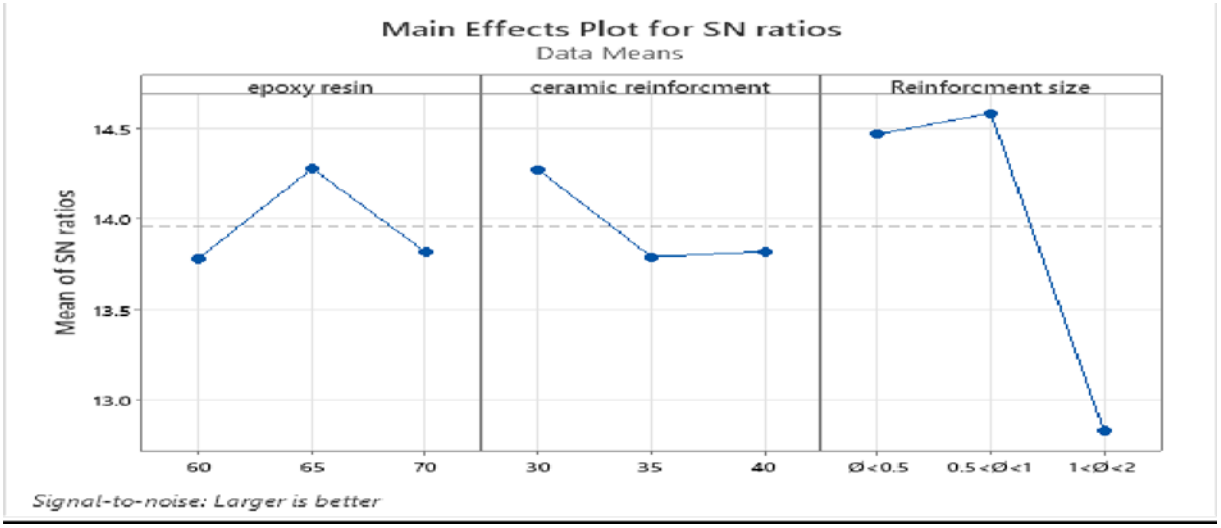
III- Larger- The Best:- calculated by equation below

$$\frac{S}{N} = -10\log\frac{1}{n}\sum\frac{1}{y^2} \quad \text{.....Equation 6}$$

For the S/N ratio of the three experiments, which are flexural strength, and dielectric strength a larger value of S/N was needed, so Equation 6 was applied.Using Taguchi Minitab software the S/N results for each response were calculated.



a)



b)

Figure 11 Main effective plot for SN ratio of water absorption a) flexural strength b) dielectric strength

As seen from Figure 11, in all the testes filler size had the highest effect on the mechanical and physical responcess than filler concentration and epoxy resin.

3.3.2 Data Normalisation

Normalization of the response data is classified into three. Such are the smaller the better, normal the better, and higher the better. Each response was used according to the desired experimental outputs. In this study for flexural, and dielectric strength "higher better response was used [18].

I- Smaller-The Better

$$\text{Equation 7}$$

II- Higher-The better

$$\text{Equation 8}$$

Where, Xi(k)=value after the grey relation generation, MinXi(k)=minimum value of Xi(k) from the kth response, MaxXi= maximum value of Xi(k) from the kth response. Using the above formulas the normalized data was calculated from the SNRA response.

3.3.3 Calculating Deviation Sequence, Δ0i(k)

After normalizing the SNRA, now the deviation sequence is calculated for each normalized data. Deviation sequence (Δ0i) is the absolute value difference between the maximum value of the normalized data, X *(K) and the first number of data normalized value X *(k). Mathematically it is expressed below[30].

$$\Delta 0_i(k) = || X_{max}^*(k) - X_i^*(k) || \quad \text{.....Equation 9}$$

Where, X *(k)=1 for all normalized values. The deviation sequence was calculated using Equation 9.

3.3.4. Calculating of Grey Relation Grades, GRG

The grey relation grade is used to measure the correlation between the reference sequence and comparability sequence[31]. The grey relation grade is the weighted average of the grey relation coefficient of multiple responses. Mathematically it was calculated using the following formula [31].

$$yi = \frac{1}{n}\sum_{k=1}^{1} (i(k) \quad \text{.....Equation 10}$$

Where γi =is grey relation grade, n= is the number of responses which is 4, (i(k)=is the grey relation coefficient. The grey relation coefficient is calculated by the following equation.

$$(i(k) = \frac{\Delta min + (\Delta max}{\Delta 0i(k) + (\Delta max} \quad \text{.....Equation 11}$$

Where Δ0i(k)= is the absolute value difference between X0(K) and Xi(k) and the deviation square calculated using Equation 10. (=is the distinguished coefficient whose value lies between zero and one, Δmin= is the minimum value of the deviation sequence, Δmax= is the maximum value of the deviation sequence.

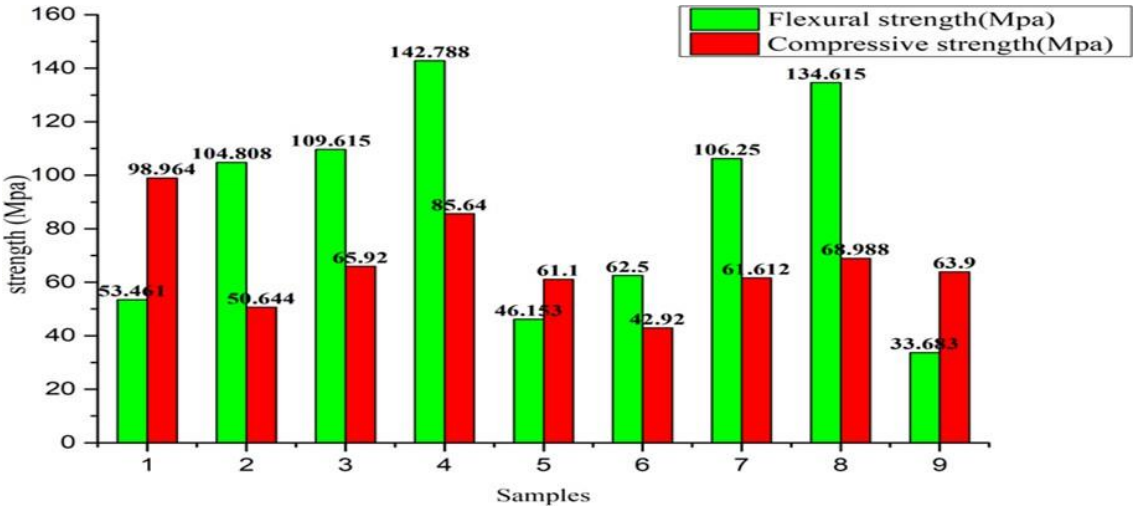
Before calculating the deviation sequence, the distinguished coefficient for multiple responses must be obtained (). Since the two experimental parameters (particle size and weight composition) have shown a significant effect, (=0.5 is used for all testes.
Now, to calculate the grey relation coefficient (GRC) Equation 11 was used. Where Δmin=0. After calculating the grey relation coefficient, now averaging those values the grey relation grade can be calculated using Equation 10.
Grey Relation Grade = Average Grey Relation Coefficient

3.3.5. Determining the Optimum Process Parameter

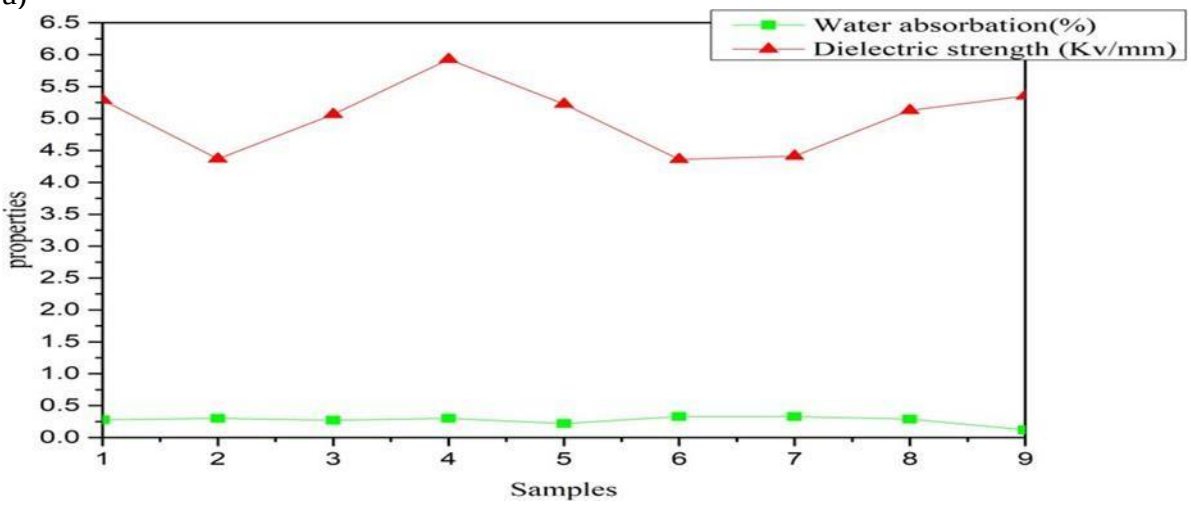
The optimum process parameter was determined by using the grey relation grade. When the grey relational grade is higher it indicates that there is a strong relation between the ideal sequence X0(k), and the given sequence Xi(k). At this stage of optimizing process parameters the higher the GRG indicates the closer is to the optimal process parameter[31]. So, based on the previous explanation ranking was given to each process parameter depending on the GRG values (see Table 3).

Exp.Num	Flexural strength (Mpa)	Dielectric strength (KV/mm)	GRG (yi)	Rank
1	63.461	5.287	0.52205	5
2	104.808	4.366	0.51735	6
3	109.615	5.065	0.61305	3
4	142.788	5.929	1	1
5	46.153	5.227	0.46985	7
6	106.25	4.359	0.39985	9
7	106.25	4.41	0.5258	4
8	134.615	5.127	0.71935	2
9	33.683	5.355	0.4675	8

As seen from Table 3, the highest value of GRG is allotted for experiment number four, which is ranked as number one. Experiment four had a ceramic particle size reinforcement of 0.5<Ø<1mm, with a 30-65%wt ceramic-resin concentration. Seeing the recorded experimental results, test sample four had the highest recorded flexural and dielectric strength of 142.78Mpa and 5.92Kv/mm respectively. Those experiments are significant in studying the mechanical and physical properties of dielectric insulators. The overall finding for all composite materials is shown in Figure 12.



a)



b)

Figure 12 Overall properties for all test samples a) mechanical response b) physical response

4. Conclusion and Recommendation

4.1. Conclusion

After successfully completing an experimental investigation into the produced composite samples, the following main findings were summarized.

1. During the flexural strength test, the bending strength was higher when ceramic reinforcement concentration was at the lowest (30wt%) regardless of reinforcement size. As reinforcement concentration increases, results have shown a decrease in bending strength for all samples. At the optimum ceramic reinforcement size, the highest flexural strength was recorded.
2. During the compressive strength test, an indirect relation between reinforcement particle size and filler ceramic concentration with compressive strength was observed. As particle size and filler concentration increases a decrease in compressive strength is seen.
3. For the moisture absorption test, high water intake by the test samples were seen when the ceramic filler size was at the highest. As filler concentration increases in the polymer matrix a decrease in water absorption is recorded.
4. During the dielectric strength test, some odd behavior was seen when the filler particle size was the smallest. However, beyond the optimum value, a decrease in dielectric strength was noticed as filler concentration and particle size increased.
5. An optimum process parameter was recorded when ceramic reinforcement size was at $0.5<Ø<1$mm in diameter with 30-65% ceramic to resin concentration. The validation experiment has shown a great agreement with the optimum process parameter.

In conclusion, the produced insulator composite was seen to meet the required standard to use the structure for pin-type insulation application. The recorded flexural strength shows a good agreement with previous researches, perhaps even exhibiting some better responses. The research has shown a new way to utilize waste material as a reinforcement to enhance the properties of a polymer material. This research has contributed to the knowledge of composite materials, especially in the way waste floor ceramic tiles can be utilized for a certain application.

4.2. Recommendations

Given the performance of the studied composite material, the following recommendations are advised to be considered for future work related to using ceramic reinforcement to polymer matrix for electrical insulation.

1. When using composite material for electrical insulation applications it is evident that there will be a development of heat beyond certain limits. This developed heat may affect the performance of the structure. To ensure the effective performance and durability of the structure it is advised to investigate the effect of heat. This specific test of heat dissipation will provide an essential insight into the effect of heat.
2. When electrical insulators are applicable for supporting a current-carrying wire, it is essential to consider current leakage. To ensure safety, it is strongly

recommended to investigate current leakage. By carrying out such a comprehensive investigation, we can contribute safer and more robust insulating material.

3. It is advisable to investigate the abrasion resistance of the composite material. Abrasion resistance is important to put an insight into the effect of wire rubbing against a pin-type insulator. the effect of fatigue can influence the service condition of the insulating material.

Finally, by putting into those recommendations in consideration, a complete investigation into all mechanical and physical properties can be done. By doing so, a complete response report can be gathered necessary to apply new composite material for electrical insulation application.

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